WATER TREATMENT SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a system and method of treating or purifying a fluid and, more particularly, to a water treatment system incorporating an electrochemical device with a reservoir system for delivering treated water to a point of use.

2. Description of Related Art

Water that contains hardness species such as calcium and magnesium may be undesirable for some uses in industrial, commercial and household applications. The typical guidelines for a classification of water hardness are: zero to 60 milligrams per liter (mg/l) as calcium carbonate is classified as soft; 61 to 120 mg/l as moderately hard; 121 to 180 mg/l as hard; and more than 180 mg/l as very hard.

Hard water can be treated by removing the hardness ion species. Examples of systems that remove such species include those that use ion exchange beds. In such systems, the hardness ions become ionically bound to oppositely charged ionic species that are mixed on the surface of the ion exchange resin. The ion exchange resin eventually becomes saturated with ionically bound hardness ion species and must be regenerated. Regeneration typically involves replacing the bound hardness species with more soluble ionic species, such as sodium chloride. The hardness species bound on the ion exchange resin are replaced by the sodium ions and the ion exchange resins are ready again for a subsequent water softening step.

Other systems have been disclosed. For example, Dosch, in U.S. Patent No. 3,148,687 teaches a washing machine including a water softening arrangement using ion exchange resins. Similarly, Gadini et al., in International Application Publication No. WO00/64325, disclose a household appliance using water with an improved device for reducing the water hardness. Gadini et al. teach of a household appliance having a control

system, a water supply system from an external source and a softening system with an electrochemical cell. McMahon, in U.S. Patent No. 5,166,220, teaches of a regeneration of ion exchange resin with a brine solution in a water softening process.

Systems and techniques that utilize electrodeionization (EDI) can be used to demineralize, purify or treat water. EDI is a process that removes ionizable species from liquids using electrically active media and an electrical potential to influence ion transport. The electrically active media may function to collect and discharge ionizable species, or to facilitate the transport of ions by ionic or electronic substitution mechanisms. EDI devices can include media having permanent or temporary charge and can be operated to cause electrochemical reactions designed to achieve or enhance performance. These devices may also include electrically active membranes such as semi-permeable ion exchange or bipolar membranes.

Continuous electrodeionization (CEDI) is a process that relies on ion transport through electrically active media or electroactive media. A typical CEDI device includes alternating electroactive semi-permeable anion and cation selective membranes. The spaces between the membranes are configured to create liquid flow compartments with inlets and outlets. A transverse DC electrical field is imposed by an external power source through electrodes at the bounds of the compartments. In some configurations, electrode compartments are provided so that reaction product from the electrodes can be separated from the other flow compartments. Upon imposition of the electric field, ions in the liquid to be treated in one compartment, the ion-depleting compartment, are attracted to their respective attracting electrodes. The ions migrate through the selectively permeable membranes into the adjoining compartments so that the liquid in the adjoining ion-concentrating compartments become ionically concentrated. The volume within the depleting compartments and, in some embodiments, within the concentrating compartments, includes electrically active media. In CEDI devices, the electroactive media may include intimately mixed anion and cation exchange resin beads. Such electroactive media typically enhances the transport of ions within the compartments and may participate as a substrate for controlled electrochemical reactions. Electrodeionization devices have been described by, for example, Giuffrida et al. in U.S. Patent Nos. 4,632,745, 4,925,541, and 5,211,823, by Ganzi in U.S. Patent Nos. 5,259,936 and 5,316,637, by Oren et al. in U.S. Patent No. 5,154,809 and by Kedem in U.S. Patent No. 5,240,579.

Other systems that can be used to demineralize water have been described. For example, Gaysowski, in U.S. Patent No. 3,407,864, teaches of an apparatus that involves both ion exchange and electrodialysis. Johnson, in U.S. Patent No. 3,755,135, teaches of a demineralizing apparatus using a DC potential.

SUMMARY OF THE INVENTION

The present invention is directed to a water purification or treatment system comprising a pressurized reservoir system fluidly connected to a point of entry, a water treatment device fluidly connected to the pressurized reservoir system, a water distribution system fluidly connected to the pressurized reservoir system and at least one point of use fluidly connected to the water distribution system.

In another aspect of the present invention, a treatment system is provided comprising a reservoir system fluidly connected to a point of entry, an electrochemical device fluidly connected to the reservoir system, a point of use fluidly connected to the reservoir system, and an auxiliary use fluidly connected downstream of the electrochemical device.

In another aspect of the present invention, a method is provided for treating water comprising introducing water to a pressurized reservoir system, transferring a portion of the water from the pressurized reservoir system to a water treatment device, removing at least a portion of any undesirable species from the water from the pressurized reservoir system in the water treatment device to produce a treated water, transferring the treated water from the water treatment device to the pressurized reservoir system and distributing a portion of the treated water from the pressurized reservoir system to a point of use.

In another aspect of the present invention, a method is provided for treating water comprising introducing water from a point of use to a reservoir system, removing at least a portion of any undesirable species from the water in the reservoir system in an electrochemical device to produce treated water and discharge water, transferring at least a portion of the treated water from the electrochemical device to the reservoir system, transferring a portion of the discharge water to an auxiliary use, and distributing a portion of the treated water from the reservoir system to a point of use.

In another aspect of the present invention, a water distribution system is provided comprising a first pretreatment system fluidly connected to a point of entry, a pressurized reservoir system fluidly connected downstream of the first pretreatment system, a second

pretreatment system fluidly connected to the pressurized reservoir system and an electrochemical device fluidly connected downstream of the second pretreatment system and to the pressurized reservoir system.

In another aspect of the present invention, a water treatment system is provided comprising means for accumulating water from a water source at a pressure above atmospheric pressure and an electrochemical device fluidly connected to the means for accumulating water.

In another aspect of the present invention, a method is provided for treating water comprising mixing water from a point of entry with a treated water to produce a mixed water, removing a portion of any undesirable species from a portion of the mixed water in an electrochemical device to produce the treated water and distributing a portion of the mixed water to a point of use.

In another aspect of the present invention, a method is provided for treating water comprising accumulating water from a point of use, removing at least a portion of any undesirable species from the water in an electrochemical device to produce treated water, and supplying at least a portion of the treated water to a household.

In another aspect of the present invention, a method is provided for treating water comprising accumulating water from a point of use at a pressure that is above atmospheric pressure, providing an electrochemical device electrochemical device, transferring at least a portion of the accumulated water to the electrochemical device, removing at least a portion of any undesirable species from the water in the electrochemical device to produce a treated water, and adjusting at least one operating parameter of the electrochemical device.

In another embodiment, the present invention provides a system comprising a fluid reservoir in thermal communication with a heat exchanger and a fluid treatment device fluidly connected to the fluid reservoir.

In another embodiment, the present invention provides a method for facilitating water treatment. The method can comprises providing a system comprising a pressurizable reservoir system that is fluidly connectable to a point of entry and an electrochemical device fluidly connected to the pressurizable reservoir system and fluidly connectable to a water distribution system.

Other advantages, novel features and objects of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings, which are schematic and are not intended to be drawn to

scale. In the figures, each identical or substantially similar component that is illustrated in various figures is represented by a single numeral or notation. For purposes of clarity, not every component is labeled in every figure, nor is every component of each embodiment of the invention shown where illustration is not necessary to allow those of ordinary skill in the art to understand the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred, non-limiting embodiments of the present invention will be described by way of example and with reference to the accompanying drawings, in which:

FIG. 1 is a process flow diagram of a water treatment system showing an in-line system with a pressurized reservoir system and a treatment device in accordance with one or more embodiments of the invention;

FIG. 2 is a schematic, sectional view through a typical electrochemical device in accordance with one or more embodiments of the present invention, illustrating the fluid and ion flow directions through depleting and concentrating compartments;

FIG. 3 is a schematic flow diagram of a water treatment system in accordance with one or more embodiments of the invention as discussed in Example 1;

FIG. 4 is a graph showing conductivity of water treated in the water treatment system exemplarily illustrated in FIG. 3 and discussed in Example 1;

FIG. 5 is a schematic flow diagram of a water treatment system in accordance with one or more embodiments of the invention as discussed in Example 2; and

FIG. 6 is a graph showing conductivity of water treated in the water treatment system exemplarily illustrated in FIG. 5 and discussed in Example 2.

DETAILED DESCRIPTION OF THE INVENTION

United States Patent Applications titled WATER TREATMENT SYSTEM AND METHOD by Wilkins et al. and filed on even date herewith; WATER TREATMENT SYSTEM AND METHOD by Ganzi et al. and filed on even date herewith; WATER TREATMENT SYSTEM AND METHOD by Freydina et al. and filed on even date herewith; WATER TREATMENT SYSTEM AND METHOD by Wilkins et al. and filed on even date herewith; WATER TREATMENT SYSTEM AND METHOD by Freydina et al.

and filed on even date herewith; WATER TREATMENT SYSTEM AND METHOD by Wilkins et al. and filed on even date herewith; and WATER TREATMENT SYSTEM AND METHOD by Jha et al. and filed on even date herewith are hereby incorporated by reference herein.

The present invention is directed to a water treatment or purification system and method of providing treated water in industrial, commercial and residential settings. The treatment system can provide treated water to a point of use by removing at least a portion of any hardness-causing species contained in water from a water source, such as municipal water, well water, brackish water and water containing foulants. Other applications of the system would be in the treatment and processing of foods and beverages, sugars, various industries, such as the chemical, pharmaceutical, food and beverage, wastewater treatments and power-generating industries. The present invention will be described using water as the fluid but should not be limited as such. For example, where reference is made to treated water, it is believed that other fluids can be treated according to the present invention. Moreover, where reference is made to a component of the system or to the method of the present invention that adjusts, modifies, measures or operates on water or water property, the present invention is believed to be applicable as well. Thus, the fluid to be treated may be a fluid that is a mixture comprising water. Accordingly, the fluid can be a liquid that can comprise water.

The water purification or treatment system in accordance with one or more embodiments of the present invention typically receives water from the water source or a point of entry and purifies the water containing at least some undesirable species before delivering the treated water to a point of use. The treatment system typically has a reservoir system in line with a water purification or treatment apparatus such as, but not limited to, an electrodeionization device, a reverse osmosis device, an electrodialysis device, a capacitive deionization device, a microfiltration device, and/or an ultrafiltration device. The treatment system, in some embodiments of the present invention, further comprises a sensor for measuring at least one property of the water or an operating condition of the treatment system. In other embodiments, the treatment system also includes a controller for adjusting or regulating at least one operating parameter of the treatment system or a component of the treatment system.

FIG. 1 shows a schematic flow diagram of a treatment system according to one embodiment of the present invention. Treatment system 10 includes a reservoir system 12

fluidly connected, typically, to a liquid source or a point of entry 14 and to a purification or treatment device 16, typically downstream of the point of entry. Treatment system 10 typically includes a point of use 18, which is typically fluidly connected downstream of reservoir system 12. In certain embodiments, treatment system 10 also has a sensor 20 and a controller 22 for controlling or regulating power source 24 which provides power to treatment device 16. Treatment device 16 typically removes at least a portion of any undesirable species from the liquid to be treated, flowing from point of entry 14, to produce treated liquid, such was treated water, for storage in reservoir system 12 and ultimate delivery to point of use 18. Undesirable species removed by treatment device 16 can be transferred to an auxiliary use or a drain 26.

In certain embodiments of the present invention, treatment system 10, as, for example, a water treatment system, further includes pretreatment system 28, which is typically fluidly connected upstream of reservoir system 12 or treatment device 16. Moreover, treatment system 10 typically also includes one or more fluid control components, such as pump 30 and valve 32.

The present invention will be further understood in light of the following definitions. As used herein, "pressurized" refers to a system or component that has a pressure, internal or applied, that is above atmospheric pressure. For example, pressurized reservoir system 12 has an internal pressure that is greater than atmospheric pressure. Pressure in the pressurized reservoir system can be created by various methods and techniques, for example, by pressurizing the water with a water pump or by elevating the water source, thus creating head pressure. Furthermore, where reference is made to "treated" water or fluid, the treated water can be softened water, low Langelier Saturation Index (LSI) water or low conductivity water. As used herein, low LSI water has a LSI of less than about 2, preferably, less than about 1, and more preferably, less than about zero. As used herein, the phrase "treatment device" or "purification device" or apparatus pertains to any apparatus that can be used to remove or reduce the concentration any undesirable species from a fluid to be treated. Such treatment apparatus include, but are not limited to, those that rely on techniques such as ion-exchange resin reverse osmosis, electrodeionization, electrodialysis, ultrafiltration, microfiltration, capacitive deionization. Further, where reference is made to an electrochemical device, such as "electrodeionization device 16," such reference is meant to be exemplary and other electrochemical devices such as, but not limited to, electrodeionization devices, electrodialysis devices, and, in some cases, capacitive

deionization devices, may be used in accordance with the principles of the present invention as long as such use is not inconsistent or contrary to operation of such devices and/or the techniques of the present invention. Although a number of apparatus may be used as a treatment device, the applicability of such apparatus is not intended to imply that each or all of the apparatus utilize the same principles but that such apparatus may be used, alone or in combination, as a treatment device in accordance with one or more systems and techniques of the present invention.

FIG. 2 schematically shows a cross-sectional view of fluid and ion flow paths through one embodiment of an electrodeionization device of the present invention. The electrodeionization module or device 16 includes ion-depleting (depleting) compartments 34 and ion-concentrating (concentrating) compartments 36, positioned between depleting compartments 34. Depleting compartments 34 are typically bordered by an anolyte compartment 38 and a catholyte compartment 40. Typically, end blocks (not shown) are positioned adjacent to end plates (not shown) to house an anode 42 and a cathode 44 in the respective compartments. In certain embodiments, the compartments include cation-selective membranes 46 and anion-selective membranes 48. The cation-selective membranes and anion-selective membranes typically comprise ion exchange powder, a polyethylene powder binder and a glycerin lubricant.

In accordance with one or more embodiments of the present invention, the cation- and anion-selective membranes are typically heterogeneous polyolefin-based membranes, which are typically extruded by a thermoplastic process using heat and pressure to create a composite sheet. However, the present invention contemplates the use of the other types of membranes including homogeneous membranes. Representative suitable ion-selective membranes include, for example, web supported using styrene-divinyl benzene with sulphonic acid or quaternary ammonium functional groups, web supported using styrene-divinyl benzene in a polyvinylidene fluoride binder, and unsupported-sulfonated styrene and quarternized vinyl benzyl amine grafts on polyethylene sheet.

Concentrating compartments 36 are typically filled with electroactive media such as cation exchange resin beads 50 and depleting compartments 34 are typically filled with a mixture of cation exchange resin beads 50 and anion exchange resin beads 52. In some embodiments, the cation exchange and anion exchange resin beads can be arranged in layers within any of the depleting, concentrating and electrode compartments so that a number of layers in a variety of arrangements can be assembled. Other configurations and/or

arrangements are believed to be within the scope of the invention including, for example, the use of mixed bed ion exchange resin beads in any of the depleting, concentrating and electrode compartments, the use of inert resin between layer beds of anionic and cationic exchange resin beads, the use of various types and arrangements of anionic and cationic resin beads including, but not limited to, those described by DiMascio et al., in U.S. Patent No. 5,858,191, which is incorporated herein by reference in its entirety.

In operation, a liquid to be treated 54, typically from an upstream water source entering the treatment system at point of entry 14, having dissolved cationic and anionic components, including hardness ion species, can be introduced into depleting compartments 34 through manifold 60, wherein the cationic components are typically attracted to the cation exchange resin beads 50 and the anionic components are attracted to the anion exchange resin beads 52. An electric field applied across electrodeionization device 16, through anode 42 and cathode 44, which are typically positioned on opposite ends of electrodeionization device 16, typically passes perpendicularly relative to the fluid flow direction. Under the influence of the electric field, cationic and anionic components in the liquid tend to migrate in a direction corresponding to their attracting electrodes. Cationic components can migrate through cation-selective membrane 46 into adjacent concentrating compartment 36.

Anion-selective membrane 48, positioned on the opposite side of concentrating compartment 36, prevents migration into adjacent compartments, thereby trapping the cationic components in the concentrating compartment. Similarly, anionic components migrate through the ion-selective membranes, but in a direction that is opposite relative to the migration direction of the cationic components. Anionic components migrate through anion-selective membrane 48, from depleting compartment 34, into adjacent concentrating compartment 36. Cation-selective membrane 46, positioned on the other side of concentrating compartment 36, prevents further migration, thus trapping anionic components in the concentrating compartment. In net effect, ionic components are removed or depleted from the liquid 54 flowing in depleting compartments 34 and collected in concentrating compartments 36 resulting in a treated water product stream 56 and a concentrate or waste stream 58.

In accordance with some embodiments of the present invention, the applied electric field on electrodeionization device 16 creates a polarization phenomenon, which typically leads to the dissociation of water into hydrogen and hydroxyl ions. The hydrogen and

hydroxyl ions regenerate the ion exchange resin beads 50 and 52 in depleting compartments 34 and in some embodiments, concentrating compartments 36, so that removal of dissolved ionic components can occur continuously and without a separate step for regenerating exhausted electroactive media.

The applied electric field on electrodeionization device 16 is typically a direct current. However, any applied electric current that creates a bias or a potential difference between one electrode and another can be used to promote migration of ionic species by, for example, ionic attraction. Therefore, an alternating current may be used, provided that there is a potential difference between electrodes that is sufficient to attract cationic and anionic species to the respective attracting electrodes. In yet another embodiment, an alternating current may be rectified, for example, by using a diode or a bridge rectifier, to convert an alternating current to a pulsating current with sufficient potential to attract the charged species.

The electroactive media, ion exchange resin beads 50 and 52, typically utilized in ion-depleting compartments 34, can have a variety of functional groups on their surface regions including, but not limited to, tertiary, alkyl amino groups and dimethyl ethanolamine. These materials can also be used in combination with materials having various functional groups on their surface regions, such as quaternary ammonium groups. Other modifications and equivalents of the electrodeionization device, as part of the water treatment system disclosed, will occur to persons skilled in the art using no more than routine experimentation. For example, various other types of electroactive media may be used such as heterogeneous and homogeneous types. Similarly, other variations in arrangements of depleting and concentrating compartments are believed to be within the scope and spirit of the invention.

Reservoir system 12 serves to store or accumulate water from point of entry 14 or a water source and can also serve to store treated water from product stream 56 from electrodeionization device 16 and can also provide water, typically treated water, or treated water mixed with water from point of entry 14, to point of use 18 through a distribution system.

In accordance with some embodiments of the present invention, reservoir system 12 comprises a pressurized vessel or a vessel that has inlets and outlets for fluid flow such as an inlet 62 and an outlet 64. Inlet 62 is typically fluidly connected to point of entry 14 and outlet 64 is typically fluidly connected to a water distribution system or a point of use 18.

Reservoir system 12 can have several vessels , each vessel, in turn, can have several inlets positioned at various locations. Similarly, outlet 64 can be positioned on each vessel at various locations depending on, among other things, demand or flow rate to point of use 18, capacity or efficiency of electrodeionization device 16 and capacity or hold-up of reservoir system 12. Reservoir system 12 can further comprise various components or elements that perform desirable functions or avoid undesirable consequences. For example, reservoir system 12 can have vessels having internal components, such as baffles that are positioned to disrupt any internal flow currents within the vessels of reservoir system 12. In some embodiments, reservoir system 12 has a heat exchanger for heating or cooling the fluid. For example, reservoir system 12 can comprise a vessel with a heating coil, which can have a heating fluid at an elevated temperature relative to the temperature of the fluid in the vessel. The heating fluid can be hot water in closed-loop flow with a furnace or other heating generating unit operation so that the heating fluid temperature is raised in the furnace. The heating fluid, in turn, raises the vessel fluid temperature by heat transfer. Other examples of auxiliary or additional components include, but are not limited to, pressure relief valves designed to relieve internal pressure of any vessels and avoid or at least reduce the likelihood of vessel rupture and thermal expansion tanks that are suitable for maintaining a desired operating pressure. The size and capacity of the thermal expansion tank will depend on factors including, but not limited to, the total volume of water, the operating temperature and pressure of the reservoir system.

In accordance with one or more embodiments of the present invention, the reservoir system is connected in or in thermal communication with the heat exchanger and, optionally, to a fluid treatment device. The fluid treatment device can be an electrodeionization device, a reverse osmosis device, an ion-exchange resin bed, an electrodialysis device, a capacitive deionization device, or combinations thereof.

In operation, reservoir system 12 is typically connected downstream of point of entry 14 and fluidly connected in-line, such as in a circulation loop, with electrodeionization device 16. For example, water from point of entry 14 can flow into inlet 62 and can mix with the bulk water contained within reservoir system 12. Bulk water can exit reservoir system 12 through outlet 64 and can be directed to point of use 18 or through pump 30 into electrodeionization device 16 for treatment or removal of any undesirable species. Treated water leaving electrodeionization device 16 can mix with water from point of entry 14 and enter reservoir system 12 through inlet 62. In this way, a loop can be formed between

reservoir system 12 and electrodeionization device 16 and feedwater from point of entry 14 can replenish water demand created by and flowing to point of use 18.

Point of entry 14 provides or connects water from a water source to the water treatment system. The water source can be a potable water source, such as municipal water source or well water or it can be a non-potable water source, such as a brackish or salt-water source. In some instances, an intermediate treatment or treatment system typically purifies the water for human consumption before it reaches point of entry 14. The water typically contains dissolved salts or ionic or ionizable species including sodium, chloride, chlorine, calcium ions, magnesium ions, carbonates, sulfates or other insoluble or semi-soluble species or dissolved gases, such as silica and carbon dioxide. Moreover, the water can contain additives, such as fluoride, chlorate and bromate.

In accordance with another embodiment of the present invention, treatment system 10 includes a fluid distribution system (not shown), which in turn connects to a point of use. The distribution system can comprise components that are fluidly connected to provide, for example, water, typically treated water, from reservoir system 12 to point of use 18. The distribution system can comprise any arrangement of pipes, valves, tees, pumps and manifolds to provide water from reservoir system 12 to one or several points of use 18 or to any component of treatment system 10. In one embodiment, the distribution system comprises a household or residential water distribution system including, but not limited to, connections to one or more points of use such, but not limited to, a sink faucet, a shower head, a washing machine and a dishwasher. For example, system 10 may be connected to the cold or hot, or both, water distribution system of a household.

Point of use 18 is typically any device or appliance that requires or demands water. For example, point of use 18 can be an appliance, such as a washing machine or a dishwasher, or can be a faucet serving to provide water to a kitchen sink or a showerhead. In another embodiment, point of use 18 comprises a system for providing water suitable for household or residential use.

In accordance with another embodiment of the present invention, water treatment system 10 also comprises a sensor, such as a water property sensor, which measures at least one physical property in treatment system 10. For example, sensor 20 can be a device that can measure water conductivity, pH, temperature, pressure, composition or flow rate. Sensor 20 can be installed or positioned within treatment system 10 to measure a particularly preferred water property. For example, sensor 20 can be a water conductivity

sensor installed in reservoir system 12 so that sensor 20 measures the conductivity of the water, which can provide an indication of the quality of the water available for service in point of use 18. In another embodiment, sensor 20 can comprise a series or a set of sensors in any various configurations or arrangements in treatment system 10. The set of sensors can be constructed, arranged or connected to controller 22 so that controller 22 can monitor, intermittently or continuously, the quality of water in, for example, reservoir system 12. In such an arrangement, the performance of treatment system 10 can be optimized as described below. Other embodiments may comprise a combination of sets of sensors in various locations throughout treatment system 10. For example, sensor 20 can be a flow sensor measuring a flow rate to a point of use 18 and further include any of a pH meter, nephelometer, composition analyzer, temperature and pressure sensor monitoring the operating condition of treatment system 10.

In accordance with another embodiment of the present invention, water treatment system 10 can further comprise a pretreatment system 28 designed to remove a portion of any undesirable species from the water before the water is introduced to, for example, reservoir system 12 or the electrodeionization device 16. Examples of pretreatment systems include, but are not limited to, reverse osmosis devices, which are typically used to desalinate brackish or salt water. A carbon or charcoal filter may be used to remove at least a portion of any chlorine, including active chlorine, or any species that may foul or interfere with the operation of electrodeionization device 16. Pretreatment system 28 can be positioned anywhere within water treatment system 10. For example, pretreatment system 28 can be positioned upstream of reservoir system 12 or downstream of system 12 but upstream of electrodeionization device 16 so that at least some chlorine species are retained in reservoir system 12 but are removed before water enters electrodeionization device 16. In accordance with further embodiments of the present invention, disinfecting and/or cleaning apparatus or systems may be utilized with the treatment system. Such disinfecting or cleaning system can comprise any apparatus that destroys or renders inactive, at least partially, any microorganisms, such as bacteria, that can accumulate in any component of the treatment system. Examples of such cleaning or disinfecting systems include those that can introduce a disinfectant or disinfecting chemical compounds, such as halogens, halogen-donors, acids or bases, as well as systems that expose wetted components of the treatment system to hot water at a temperature capable of sanitization. In accordance with still further embodiments, of the present invention, the treatment system can include final stage or post

treatment systems or subsystems that provide final purification of the fluid prior to delivery at a point of use. Examples of such post treatment systems include, but are not limited to those that expose the fluid to actinic radiation or ultraviolet radiation, and/or ozone or remove undesirable compounds by microfiltration or ultrafiltration. Thus, in accordance with one or more embodiments of the present invention, the treatment system may be utilized for household service and installed, for example, under a sink and provide treated water, which is treated by exposure to ultraviolet radiation, before being delivered to a point of use, such as a faucet.

In accordance with other embodiments of the present invention, treatment system 10 can further comprise a controller 22 that is capable of monitoring and regulating the operating conditions of treatment system 10 and its components. Controller 22 typically comprises a microprocessor-based device, such as a programmable logic controller (PLC) or a distributed control system that receives or sends input and output signals to components of treatment system 10. In one embodiment, controller 22 can comprise a PLC that sends a signal to power source 24, which supplies power to electrodeionization device 16 or can provide a signal to a motor control center that provides power to pumps 30. In certain embodiments, controller 22 regulates the operating conditions of water treatment system 10 in open-loop or closed-loop control scheme. For example, controller 22, in open-loop control, can provide signals to the water treatment system such that water is treated without measuring any operating condition. Controller 22 can control the operating conditions in closed-loop control so that operating parameters can be adjusted depending on an operating condition measured by, for example, sensor 20. In yet another embodiment, controller 22 can further comprise a communication system such as a remote communication device for transmitting or sending the measured operating condition or operating parameter to a remote station.

In accordance with another embodiment of the present invention, controller 22 can provide a signal that actuates a valve 32 in treatment system 10 so that fluid flow in treatment system 10 is adjusted based on a variety of parameters including, but not limited to, the quality of water from point of entry 14, the quality of water to point of use 18, the demand or quantity of water to point of use 18, the operating efficiency or capacity of electrodeionization device 16, or any of a variety of operating conditions, such as the water conductivity, pH, turbidity, composition, temperature, pressure and flow rate. In one embodiment, controller 22 receives signals from sensor 20 so that controller 22 is capable of

monitoring the operating parameters of treatment system 10. For example, sensor 20 can be a water conductivity sensor positioned within reservoir system 12 so that the water conductivity in reservoir system 12 is monitored by controller 22. Controller 22 can, based on, for example, the water quality measured by sensor 20, control power source 24, which provides an electric field to electrodeionization device 16. So, in operation, controller 22 can increase or decrease or otherwise adjust the voltage and current or both supplied from power source 24 to electrodeionization device 16. Controller 22 typically includes algorithms that can change an operating parameter of treatment system 10 based on one or more measured properties of the liquid flowing in the system. Thus, in some embodiments of the present invention, controller 22 can increase or decrease or otherwise adjust the period between operating cycles of electrodeionization device 16, such as, but not limited to, cycles of reversing applied electric field and the associated fluid flow.

In accordance with another embodiment of the invention, controller 22 can reverse the direction of the applied current from power source 24 to electrodeionization device 16 according to a predetermined schedule or according to an operating condition, such as the water quality or any other operating parameter. Polarity reversal has been described by, for example, Giuffrida et al., in U.S. Patent No. 4,956,071, which is incorporated herein by reference in its entirety.

Controller 22 can be configured or configurable by programming or can be self-adjusting such that it is capable of maximizing, for example, any of the service life and the efficiency of or reducing the operating cost of treatment system 10. For example, controller 22 can comprise a microprocessor having user-selectable set points or self-adjusting set points that adjusts the applied voltage and current to electrodeionization device 16, the flow rate through the concentrating and depleting compartments of the electrodeionization device or the discharge flow rate to drain 26 from the electrodeionization device or the pretreatment system or both. Other modifications and equivalents of the controller, as part of the water treatment system disclosed, will occur to persons skilled in the art using no more than routine experimentation. For example, the use of adaptive, self-adjusting, or self-diagnosing controllers capable of changing the operating parameters based on a variety of input parameters such as rate of water use or time of water use, are believed to be within the scope and spirit of the invention.

In accordance with another embodiment of the present invention, controller 22 can calculate a control parameter that can be used to adjust or vary a control signal to a

component of the water treatment system. For example, controller 22 can calculate a LSI based on the measured operating conditions of the streams of the water treatment system. LSI can then be used in another or the same control loop, in the same or another controller, as an input variable that can be compared to a set-point and generate an output signal that actuates, adjusts or otherwise regulates a component of the water treatment system. LSI can be calculated according to, for example, ASTM D 3739.

Controller 22 can incorporate dead band control to reduce the likelihood of unstable on/off control or chattering. Dead band refers to the range of signal outputs that a sensor provides without necessarily triggering a responsive control signal. The dead band may reside, in some cases, intrinsically in the sensor or may be programmed as part of the control system, or both. Dead band control can avoid unnecessary intermittent operation by smoothing out measurement excursions. Such control techniques can prolong the operating life or mean time before failure of the components of treatment system 10. Other techniques that can be used include the use of voting, time-smoothing or time-averaging measurements or combinations thereof.

In accordance with another embodiment of the present invention, discharge water, typical from waste stream 58, to auxiliary use can serve or provide additional or secondary benefits. For example, waste stream 58, rather than going to drain 26, may be used to provide, for example, irrigating water to any residential, commercial or industrial use, such as for irrigating, for recycling or for recovery of collected or concentrated salts. In yet another embodiment, the treatment system includes a mixing system that is fluidly connected to at least one of the distribution system and the reservoir system. The mixing or blending system can include a fluid connection in the distribution system as well as a fluid connection to the point of entry. The mixing system can provide fluid mixing of, for example, untreated water with treated water to produce service water that can be used at the point of use. The mixing system can include at least one a tee and a mixing tank, or both, that fluidly connects an outlet of the reservoir system and the point of entry. The mixing system, in some cases, can include a valve that regulates the flow of any of the untreated water stream and the treated water stream flowing to the point of use. In another embodiment, the valve can be a proportional valve that mixes the treated water with untreated water according to a predetermined ratio. In another embodiment, the valve can be actuated by the controller depending on any of the flow rate, the water property and the particular service associated with the point of use. For example, if a low hardness water is

required by the point of use, then the controller can regulate the amount of untreated water, if any, that can be mixed with treated water by actuating a valve, which regulates the flow rate of the untreated water, in closed-loop control with a sensor measuring the conductivity of the mixed water stream. In another embodiment, the valve can regulate the flow rate of the treated water that would be mixed with the untreated water according to the requirements of the point of use. In another embodiment, the treatment device can be operated to reach a set-point that is lower than any required by various points of use so that any mixing of treated water with untreated water can produce service water that satisfies the particular requirements of each point of use. Those of ordinary skill should recognize that the present the treatment system can be adjustable to accommodate fluctuations in demand as well as variations in water quality requirements. For example, the present invention can provide a water treatment system that can produce low LSI water, which would be available to the system as a whole, during extended idle periods. The low LSI water, in some embodiments, can be used to flush the wetted components of the treatment system, which can reduce the likelihood of scaling and should increase the service life of the components, individually, as well as the treatment system as a whole. In accordance with some embodiments, the present invention provides a system for producing treated liquids, such as water, having a low conductivity. As used herein, a low conductivity liquid has a conductivity of less than about 300 μS/cm, preferably less than about 220 μS/cm and more preferably, less than about 200 μS/cm.

The treatment system can comprise a fluid circuit that can provide treated or, in some cases, softened water or, in other cases, low conductivity water or low LSI water, to an electrode compartment of the treatment device such as an electrodeionization device. The fluid circuit can comprise fluid connections from a treated water source to the electrode compartments of the electrodeionization device. The fluid circuit can also comprise a pretreatment unit, such as a carbon filter that can remove any species, such as chlorine, which can interfere with the operation of the electrodeionization device. The fluid circuit can also include fluid connections to at least one of the depleting and the concentrating compartments of the electrodeionization device, for example, downstream of the pretreatment unit. The fluid circuit connections, in accordance with one or more embodiments of the present invention provides connections so that fluid exiting the electrode compartments can be, for example, mixed together or mixed with fluid to be treated in the depleting compartment. The fluid circuit can also comprise pumps and valves

that can direct fluid flow to and from the electrodeionization device as well as to and from the reservoir system. In some cases, the fluid circuit is arranged to provide fluid connections that creates parallel flow paths through the electrode compartments of the electrodeionization device. Other arrangements and configurations are considered to be within the scope of the present invention including, for example, serial flow paths from one electrode compartment to the other, the use of single, multiple or dedicated pretreatment units as well as multiple or staged treatment units including, but not limited to, reverse osmosis, ion exchange and electrodeionization devices, or combinations thereof, in the fluid circuit.

The treatment system can comprise a fluid circuit that provides fluid connections from a depleting compartment to at least one electrode compartment of the electrodeionization device. Such an arrangement can provide treated water, preferably water having low LSI or low conductivity, or both, to the electrode compartment. The fluid circuit can be arranged so that the fluid flow paths can be in series or in parallel through the electrode compartments. The fluid circuit can also comprise fluid connections to allow the fluid that would exit the electrode compartment to be delivered to a point of use via, for example, a water distribution system or to a reservoir system, or to both. In some arrangements, the fluid circuit can comprise fluid connections so that untreated fluid can be mixed with fluid that would exit any of electrode compartments; the mixture can be delivered to the point of use. In another embodiment, the fluid circuit can further comprise fluid connections to and from a reservoir system so that, for example, treated fluid that would exit the depleting compartment can be transferred to the reservoir system and mixed with untreated fluid from the point of entry and the mixture can be delivered to the point of use and, optionally, to the electrode compartments of the electrodeionization device in parallel or series flow paths. Other arrangements and combinations including, for example, the mixing of treated and untreated water to produce a mixed electrode compartment flushing fluid is considered to be within the scope of the present invention.

The present invention will be further illustrated through the following examples, which are illustrative in nature and are not intended to limit the scope of the invention.

Example 1

An in-line pressurized water treatment system in accordance with one or more embodiments of the systems and techniques of the present invention, schematically shown in FIG. 3, was evaluated for performance. The water treatment system 10 had an electrodeionization module 16 with a pretreatment system (not shown) and a pressurized storage vessel 12. Water, from point of entry 14, was introduced into pressurized vessel 12 and was circulated through electrodeionization module 16. The water treatment system was controlled by a programmable controller (not shown) based on a measured water conductivity, as measured by sensors 20b and 20c, upstream of an inlet 62 and downstream of an outlet 64 of pressurized vessel 12.

Electrodeionization device 16 comprised of a 10-cell pair stack with 13-inch flowpaths. Each cell was filled with about 40 % AMBERLITE® SF 120 resin and about 60 % AMBERLITE® IRA 458 resin, both available from Rohm & Haas Company, Philadelphia, Pennsylvania. The electrodeionization device had an expanded titanium electrode, which was coated with ruthenium oxide. The pretreatment system comprised of an aeration type iron-filter with a 25-micron rating, a 20 inch x 4 inch sediment filter and a 20 inch x 4 inch carbon block filter. Pressurized vessel 12 was about a 10 inch diameter fiberglass vessel with about a 17-gallon capacity. The pressurized vessel was fitted with a valve head and a center manifold pipe.

The concentrate stream leaving the electrodeionization device was partially circulated and partially rejected to a drain 26 by regulating valves 32b, 32c, 32e, 32f, 32g, 32h, 32 j and 32l. Make-up water, from point of entry 14, was fed into the circulating stream to compensate for any water that was rejected to drain 26 by actuating valves 32b, 32c and 32d, in proper sequence. Treated water exited electrodeionization device 16 and was returned to vessel 12 through a return fluid circuit having a liquid conduit and valves 32i and 32k.

The flow rate of treated water to a point of use 18 from outlet 64 of pressurized vessel 12 was regulated by adjusting valve 32a. Several sensors measuring operating conditions and water properties were installed throughout water treatment system 10 including pressure indicators 20d, 20f, 20g, 20h and 20i, flow rate indicators 20a, 20e, 20j and 20k and conductivity sensors 20b, 20c and 20l.

The controller was a MICROLOGIX™ 1000 programmable controller available from Allen-Bradley Company, Inc., Milwaukee, Wisconsin, which was used to control the

valve sequencing as well as to monitor and record the operating conditions of the system. The controller fluidly isolated the electrodeionization device when a set-point was reached. The controller started the electrodeionization device depending on whether a flow switch signal triggered operation or when the water conductivity of the outlet stream leaving the pressurized vessel was higher than the set point. The feed from the electrodeionization device was circulated from the pressurized vessel via a second feed pump. The polarity of the electric field applied to the electrodeionization device was reversed by the controller every 15 minutes.

The water treatment system was operated until a set point was reached. The applied voltage to the electrodeionization device was about 50 volts. The flow rate through the electrodeionization device was maintained at about 2000 ml/min. Tables 1 and 2 summarize the measured properties of the various streams of the water treatment system at the start and end of the test, respectively. Notably, the data presented in Table 1 showed that the initial feed stream into electrodeionization device 16, with a conductivity of about 462 μS/cm, was treated to produce an initial dilute stream having a conductivity of about 374 μS/cm without a substantial pH change. At the end of the run, feed water was treated from a conductivity of about 255 μS/cm to produce a dilute stream with a conductivity of about 158 μS/cm. Notably, the lower conductivity of the feed stream at the end of the test run reflected the effect of circulation, which effectively removed undesirable species over several passes.

Table 1. Stream properties at the start of the test run.

	Feed Stream	Reject Stream	Dilute Stream
pH	7.23	7.51	7.41
Conductivity (μS/cm)	462	1394	374

Table 2. Stream properties at the end of the test run.

	Feed Stream	Reject Stream	Dilute Stream
pH	6.79	7.77	6.62
Conductivity (μS/cm)	255	1024	158

FIG. 4 shows the conductivity of the water along with the applied current through the electrodeionization device during the test run. The conductivity of the treated water

from the electrodeionization device, labeled as dilute, was reduced to less than about 175 μS/cm in less than about 45 minutes. FIG. 4 also shows that the conductivity of the product stream, to service such as a point of use and labeled as tank outlet and dilute feed, was reduced to less than about 300 μS/cm. Furthermore, FIG. 4 shows that the applied current was reduced, as expected, with decreasing concentration of hardness species. Thus, the water treatment system of the present invention reduced the hardness, as measured by conductivity, by about 70 % while delivering about 80 gallons per day.

Example 2

An in-line pressurized water treatment system in accordance with one or more embodiments of the present invention, schematically shown in FIG. 5, was evaluated for performance. The water treatment system 10 had an electrodeionization module 16 and a pressurized storage vessel 12. Water, from point of entry 14, was introduced into pressurized storage vessel 12 through inlet 62 and was circulated using pumps 30a and 30b and treated through pretreatment units 28a and 28b and electrodeionization module 16. The water treatment system was controlled by a programmable controller (not shown) based on the measured water conductivity, as measured by sensors any of 20a, 20b, and 20c.

Electrodeionization device 16 comprised of a 10-cell pair stack with flowpaths that were about 7.5 inches long and about 2.5 inches wide. Each cell was filled with about 40 % AMBERLITE® SF 120 resin and about 60 % AMBERLITE® IRA 458 resin, both available from Rohm & Haas Company, Philadelphia, Pennsylvania. The electrodeionization device had an expanded titanium electrode coated with ruthenium oxide.

The controller was a MICROLOGIX™ 1000 programmable controller available from Allen-Bradley Company, Inc., Milwaukee, Wisconsin. The electrodeionization device was set to start up either by a flow switch signal or when the water conductivity of the outlet stream leaving the pressurized vessel was higher than a set point. The electrodeionization device operated until the conductivity reached the set point. The feed from the electrodeionization device was circulated from the pressurized vessel via a second feed pump. The polarity of the electric field applied to the electrodeionization device was reversed about every 15 minutes. In addition to controlling the components of electrodeionization device 16, the PLC collected, stored and transmitted measured data from sensors 20a, 20b, 20c and 20d.

Pressurized vessel 12 was a 10-inch diameter fiberglass vessel with a 30-gallon capacity. Pressurized vessel 12 was fitted with a valve head and a center manifold pipe. The concentrate stream leaving the electrodeionization device was partially circulated and partially rejected to a drain 26 by regulating valves 32c, 32d, 32e, 32f and 32g. Make-up water, from point of entry 14, was fed into the circulating stream to compensate for any water that was rejected to drain 26. The pretreatment system comprised of an aeration iron-filter with a 25-micron rating, a 20 inch x 4 inch sediment filter and a 20 inch x 4 inch carbon block filter.

In the one flow direction, water from pressure vessel 12 was pumped by pump 30a, from pressure vessel 12 through valve 32c, to pretreatment unit 28a before being introduced to the depleting compartments (not shown) of electrodeionization device 16. Treated water from electrodeionization device 16 was directed by valve 32f to storage in pressure vessel 12. Fluid collecting removed ionic species was circulated by pump 30b through pretreatment unit 28b, the concentrating and electrode compartments (not shown) of electrodeionization device 16 and valve 32e. When the direction of the applied electric field was reversed, the flow directions were correspondingly adjusted so that pump 30a, pretreatment unit 28a, and valves 32c and 32f circulated the concentrate stream, which was accumulating ionic species, while flowing through the concentrating and electrode compartments of electrodeionization device 16. Similarly, water to be treated was pumped from pressure vessel 12 using pump 30b through valve 32d to pretreatment unit 28b before being introduced and treated in the depleting compartments of electrodeionization device 16. From electrodeionization device 16, treated water was directed by valve 32e to flow into pressure vessel 12.

The flow rate of treated water, as measured by flow indicator 20d, to a point of use 18 from outlet 64 of pressurized vessel 12 was regulated by adjusting valves 32a and 32b. To discharge the concentrate stream, valve 32g was operated as necessary. Water from point of entry 14 was used to replace fluid that was discharged to drain 26. The water treatment system was operated until a target set point of about 220 μS/cm was reached and stable for about one minute. The applied voltage to the electrodeionization device was about 46 volts. The flow rates into the depleting and concentrating compartments were maintained at about 4.4 liters per minute. The reject flow rate was controlled to discharge about 270 ml of the concentrate stream about every 30 seconds. The pressure in the vessel was about 15 psig to about 20 psig.

FIG. 6 shows the measured conductivity of the various streams in the water treatment system, against run time. Tables 3 and 4 summarize the measured properties of the various streams of the water treatment system at the start and end of the test, respectively. The data presented in Table 3 showed that the initial feed stream, labeled as tankout conductivity in FIG. 6, into electrodeionization device 16 with a conductivity of about 412 μS/cm was treated to produce an initial dilute stream, labeled as stackout conductivity in FIG. 6, having a conductivity of about 312 μS/cm, without a substantial pH change. Similarly, at the end of the test run, water having a conductivity of about 221 μS/cm was treated to produce lower conductivity water of about 164 μS/cm without a substantial pH change.

As similarly noted in Example 1, the lower conductivity of the feed stream at the end of the test run reflected the effect of circulation, which effectively removed undesirable species over several passes. Thus, this example shows that the treatment system of the present invention, schematically illustrated in FIG. 5, can treat water that is suitable for household or residential use.

Table 3. Stream properties at the start of the test run.

	Feed Stream	Reject Stream	Product Stream
pH	8.19	8.3	8.02
Conductivity (μS/cm)	412	944.9	312.0

Table 4. Stream properties at the end of the test run.

	Feed Stream	Reject Stream	Product Stream
pH	8.37	8.33	7.75
Conductivity (μS/cm)	221	833.8	164

Those skilled in the art would readily appreciate that all parameters and configurations described herein are meant to be exemplary and that actual parameters and configurations will depend upon the specific application for which the systems and methods of the present invention are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific

embodiments of the invention described herein. For example, those skilled in the art may recognize that the present invention may further comprise a network of systems or be a component of a system such as a household or residential management system. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, the invention may be practiced otherwise than as specifically described. The present invention is directed to each individual feature, system, or method described herein. In addition, any combination of two or more such features, systems or methods, if such features, systems or methods are not mutually inconsistent, is included within the scope of the present invention.

What is claimed is: